NSTX

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ELM suppression through modification of edge profiles with lithium wall coatings in NSTX

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and the NSTX Research Team

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21-25 June 2010

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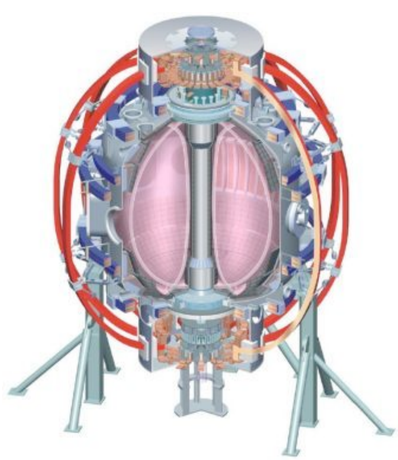

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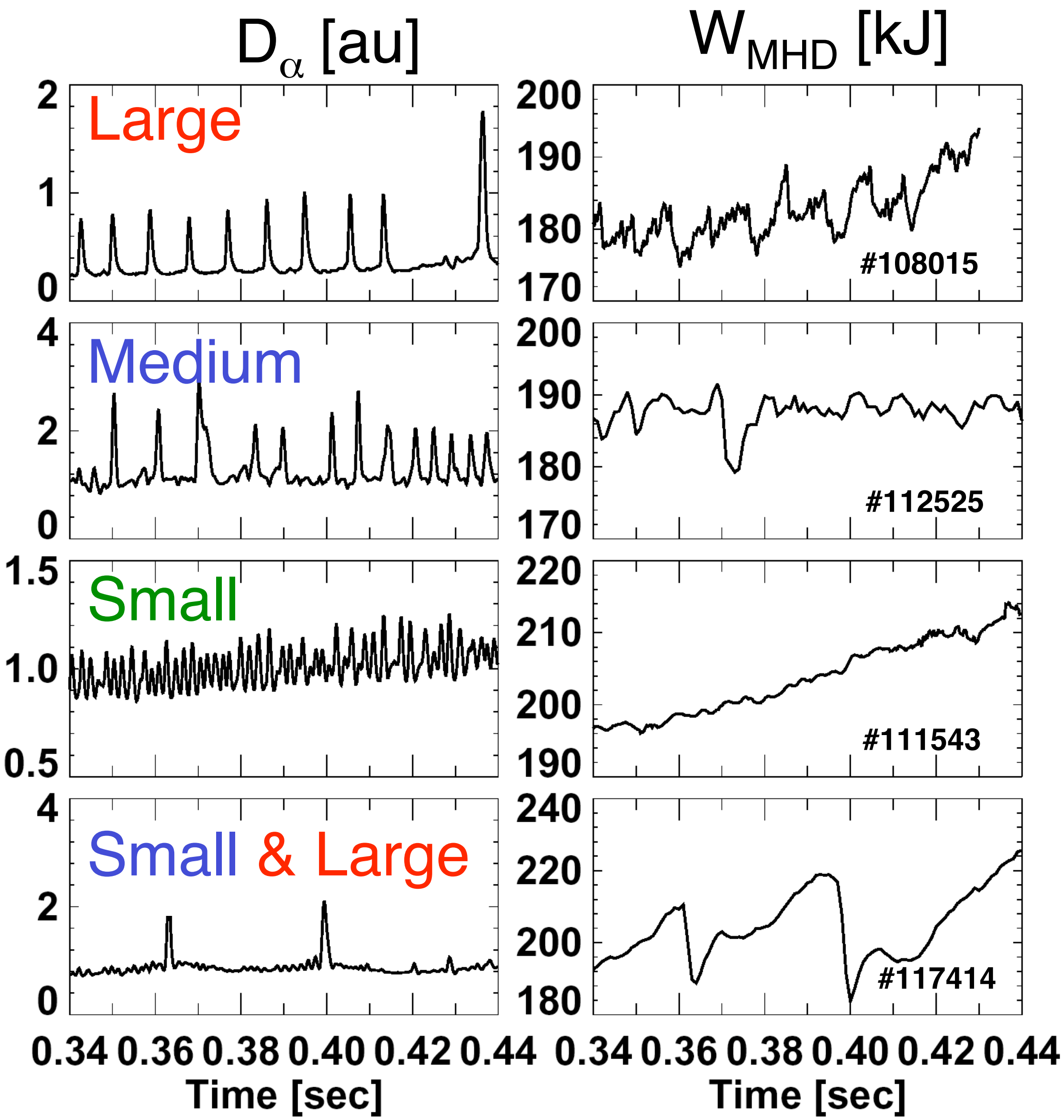
Lithium wall coatings used in NSTX to control recycling and edge density

- End points of a well-controlled lithium coating sequence
  - Edge density and temperature profile modifications with lithium, and inferred changes in cross-field transport
- Edge pressure profile modifications and stability calculations

Edge localized modes (ELMs) observed in many non-lithium NSTX H-mode discharges



$\Delta W_{MHD}/W_{MHD} \sim$ 3-20%

$\Delta W_{MHD}/W_{MHD} \sim$ 1-5%

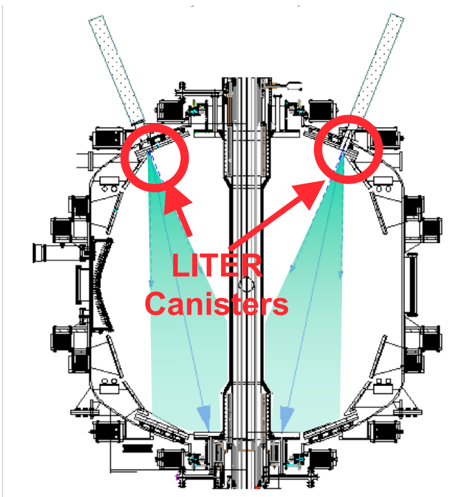
$\Delta W_{MHD}/W_{MHD} \leq$ 1%

$\Delta W_{MHD}/W_{MHD} \leq$ 30%

R. Maingi, JNM 2005

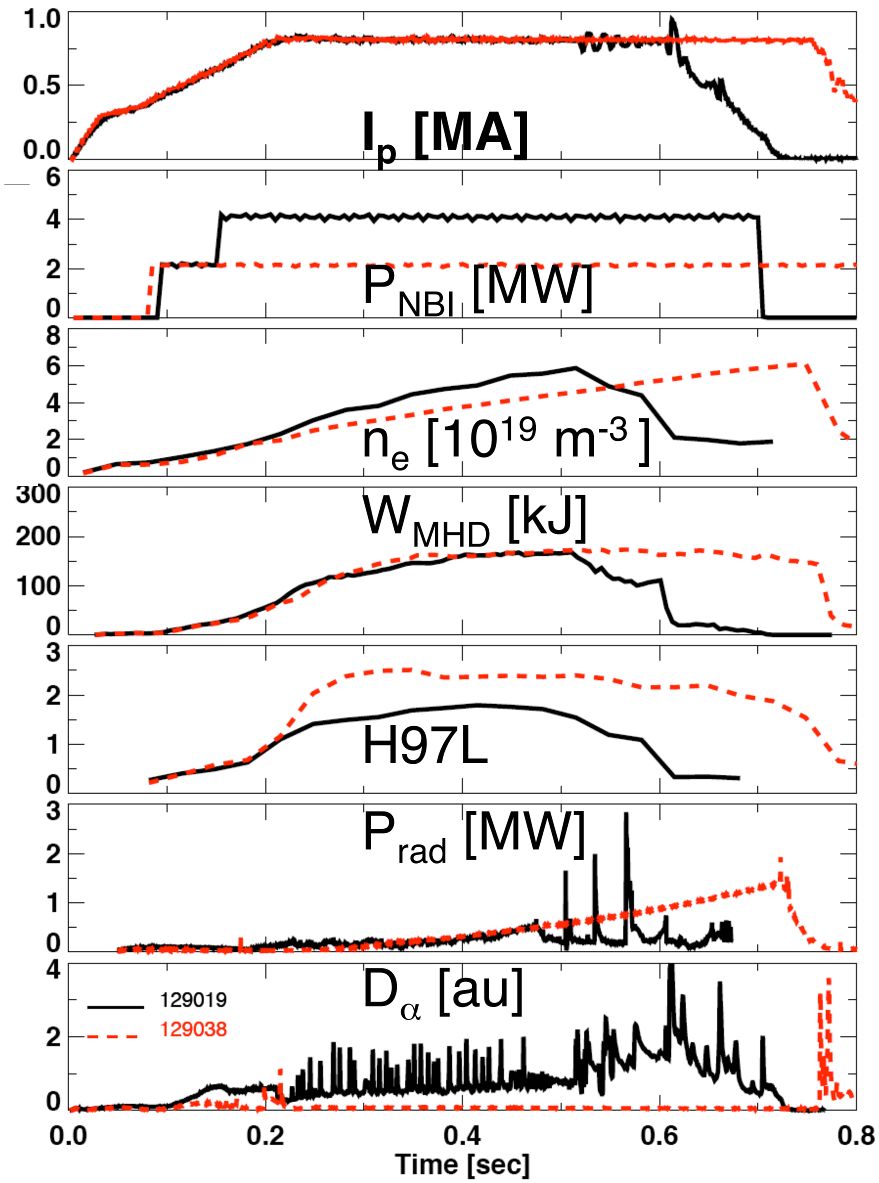
ELM-free H-mode induced by lithium wall coatings

Predicted* by L. Zakharov in 2005



~ 700mg Li before 129038

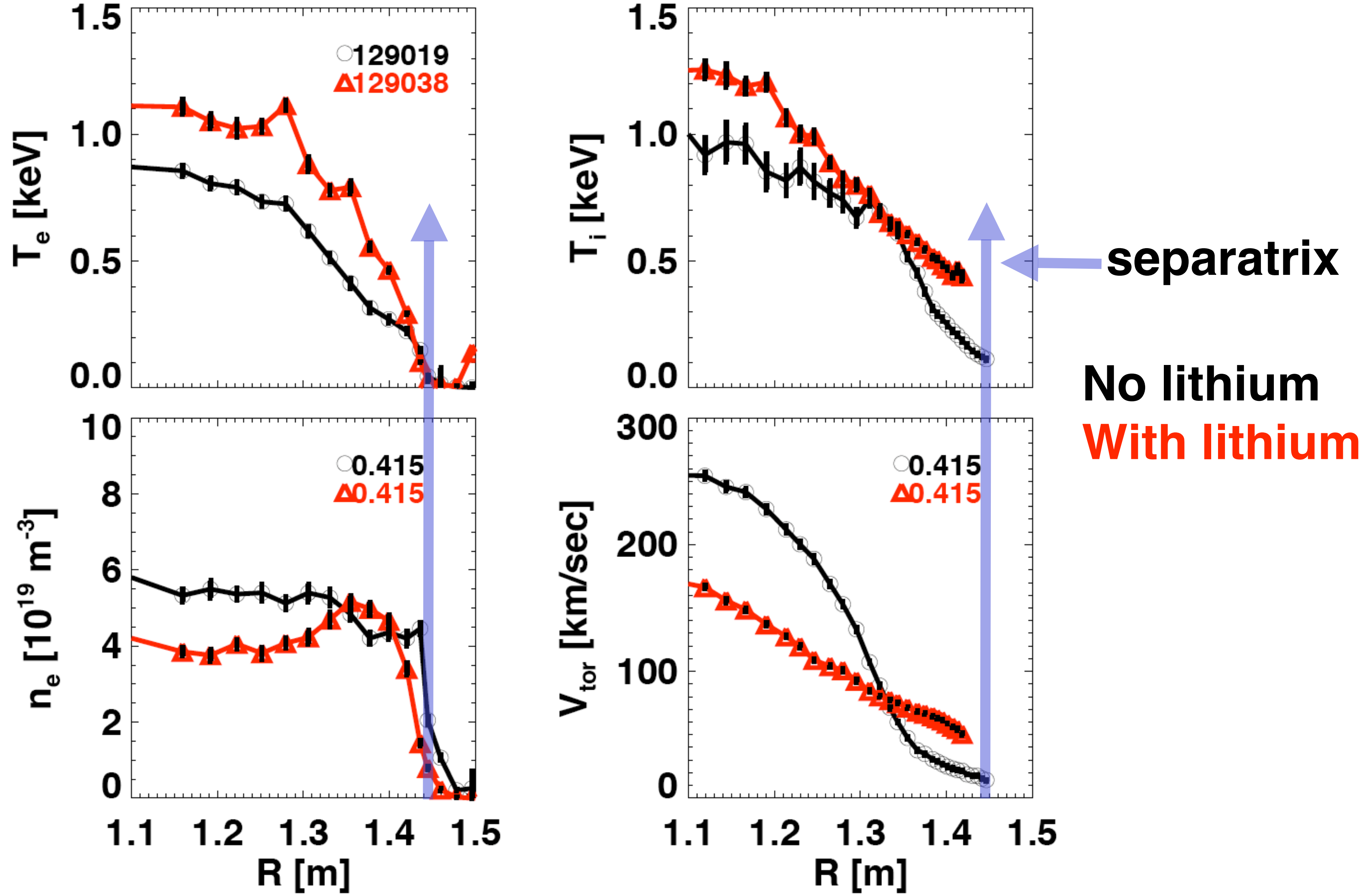
* L. Zakharov, JNM 2007



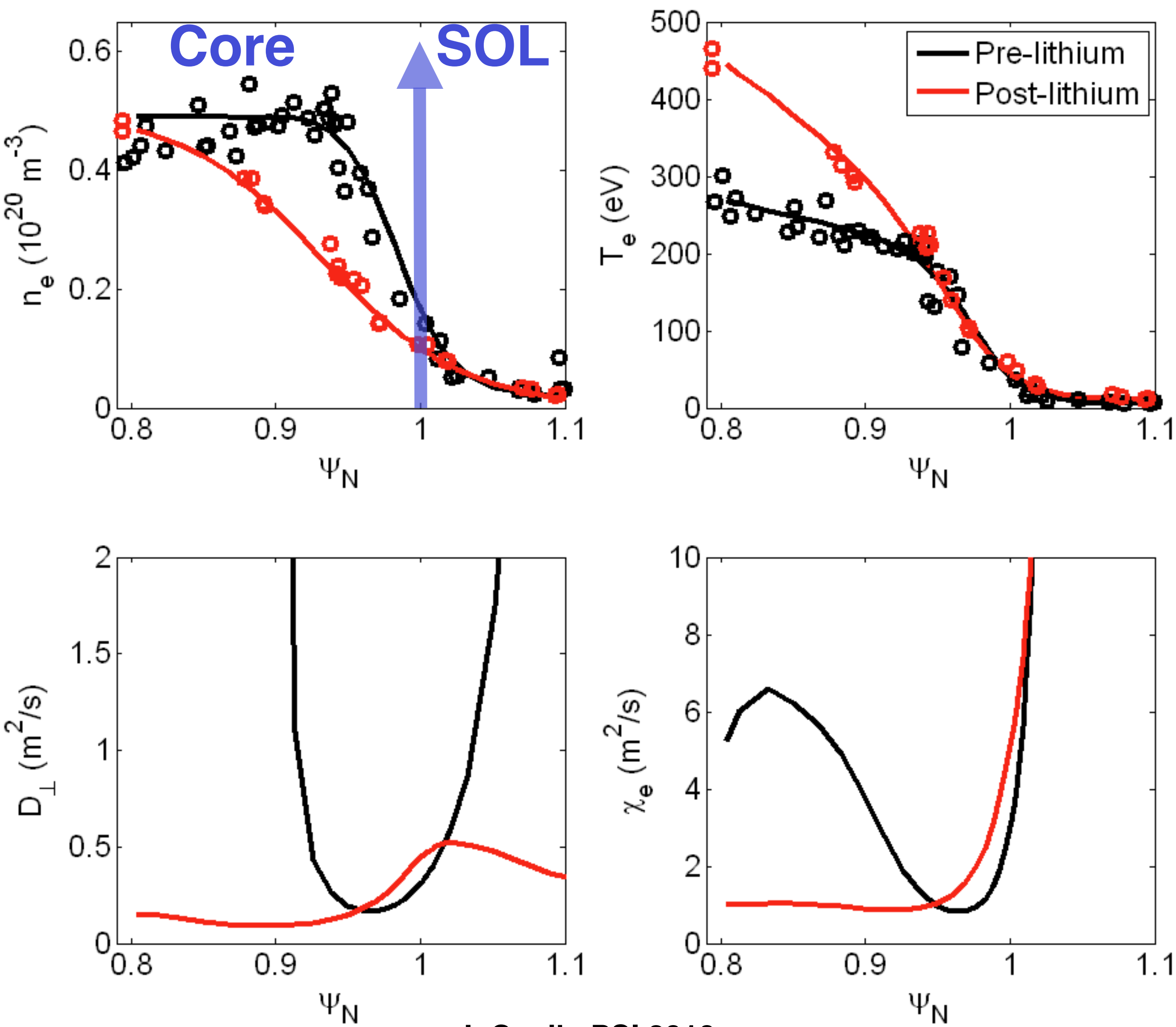
- Without-Li, With Li
- Lower NBI to avoid β limit
- Lower n_e
- Similar stored energy
- H-factor 40%↑
- Higher P_{rad} /P_{heat}
- ELM-free, reduced divertor recycling

R. Maingi, PRL 2009

T_e, T_i increased and edge n_e decreased with lithium coatings



Profiles in discharges with lithium wall coatings require recycling coefficient *and* transport change



R_p=0.98, P=3.7 MW

R_p=0.92, P=1.9 MW

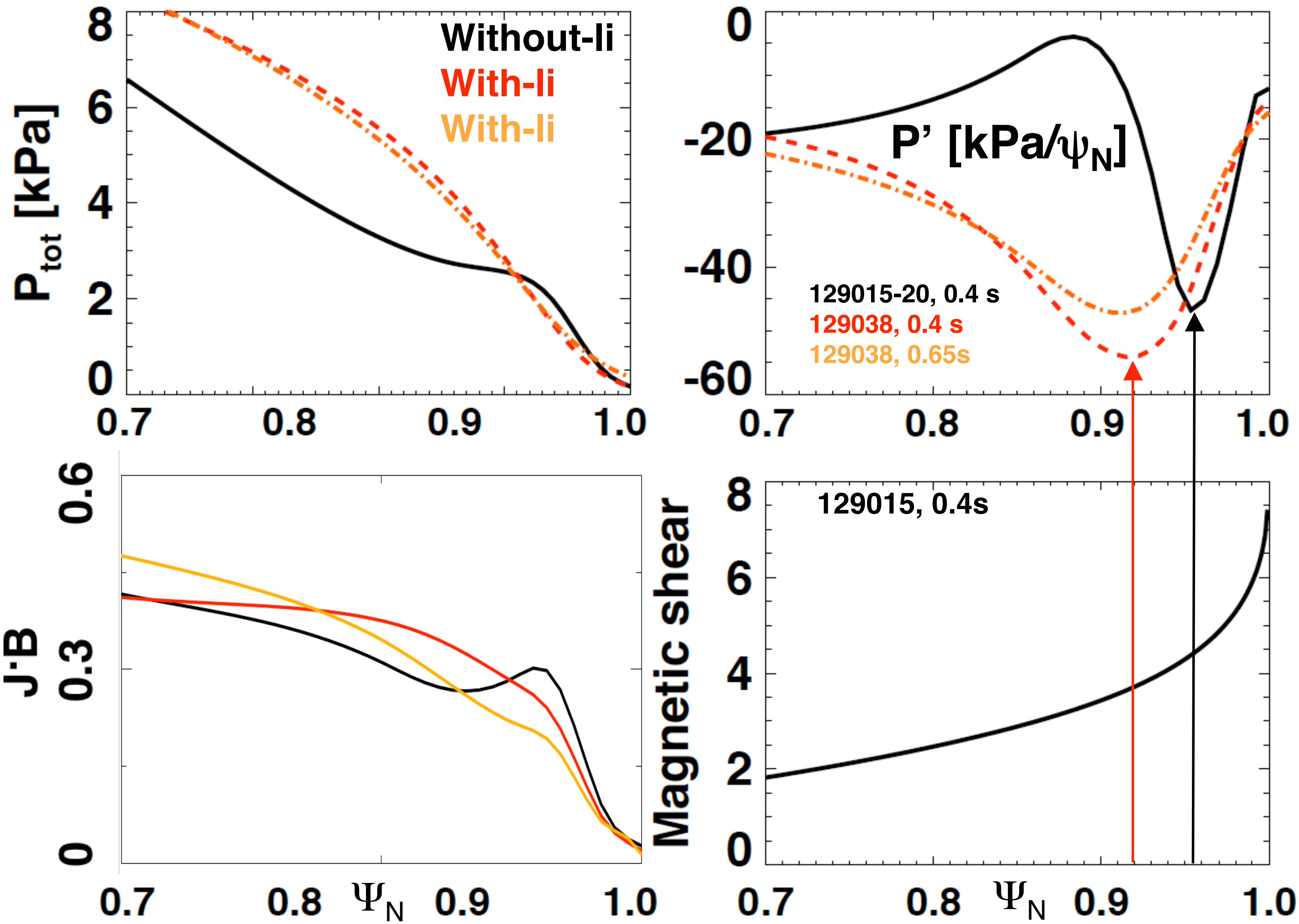
(SOLPS)

J. Canik, PSI 2010

Edge stability analysis procedure

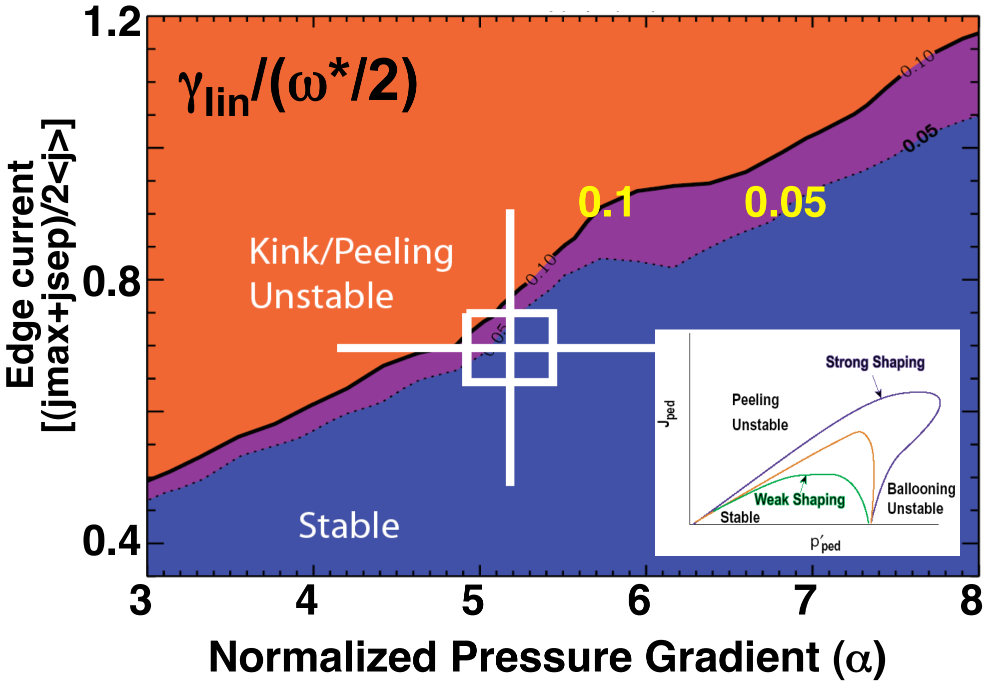
- EFIT run at Thomson profile times for ψ_N mapping
- Profile fitting of multiple time slices with standard procedures used as target for kinetic EFITs
  - Pre-lithium discharge profiles from last 20% of ELM cycle selected
  - Post-lithium discharge profiles used in 100-200 msec windows
- Free boundary kinetic EFITs run to match kinetic pressure profiles
  - Edge bootstrap current computed from Sauter neoclassical model
    - No direct measurement ➡ biggest uncertainty
  - Stability evaluated with PEST code
- Fixed boundary kinetic EFITs run with variations of edge pressure gradient and edge current
  - Stability boundary evaluated with ELITE code

Peak edge pressure gradient and bootstrap current moved to region of reduced magnetic shear

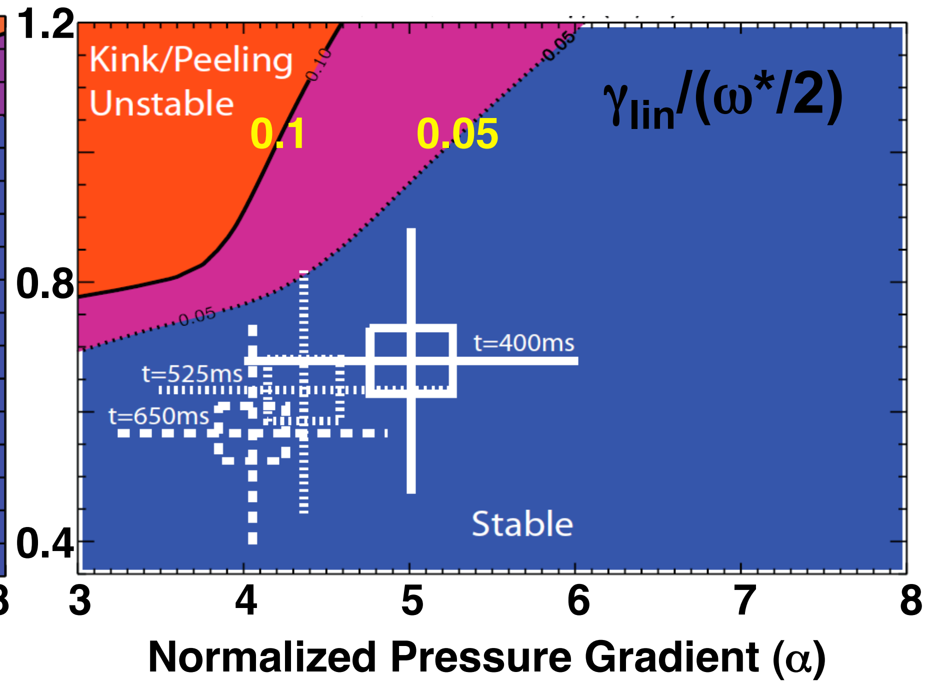


Pre-lithium edge profiles close to kink/peeling instability threshold (ELITE)

No lithium - 'varyped' EFITs



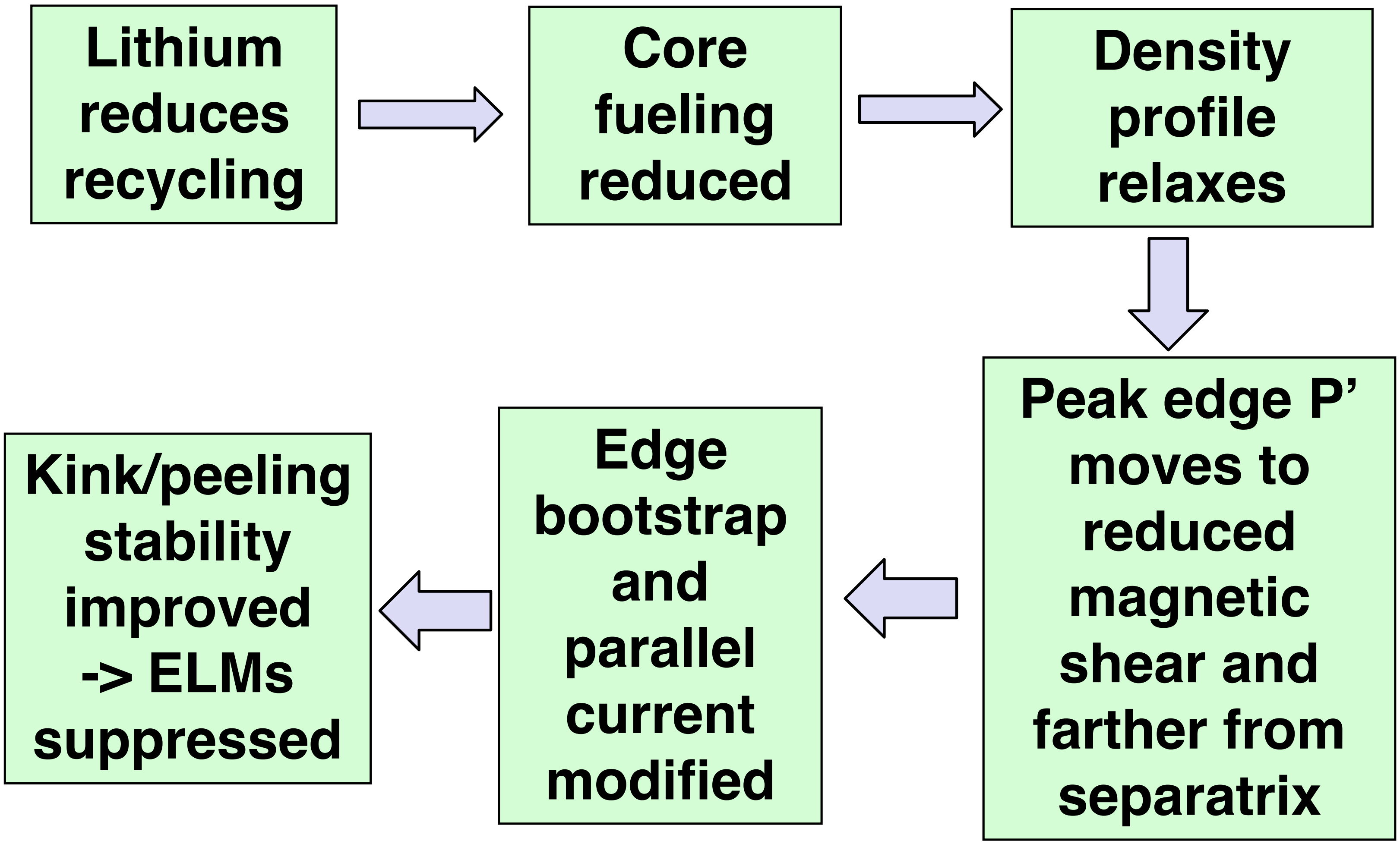
With lithium –'varyped' EFITs



- Low n=1-5 pre-cursor oscillations observed before ELM crash

R. Maingi, PRL 2009

Density profile modification to lithium pumping the key in changing edge stability



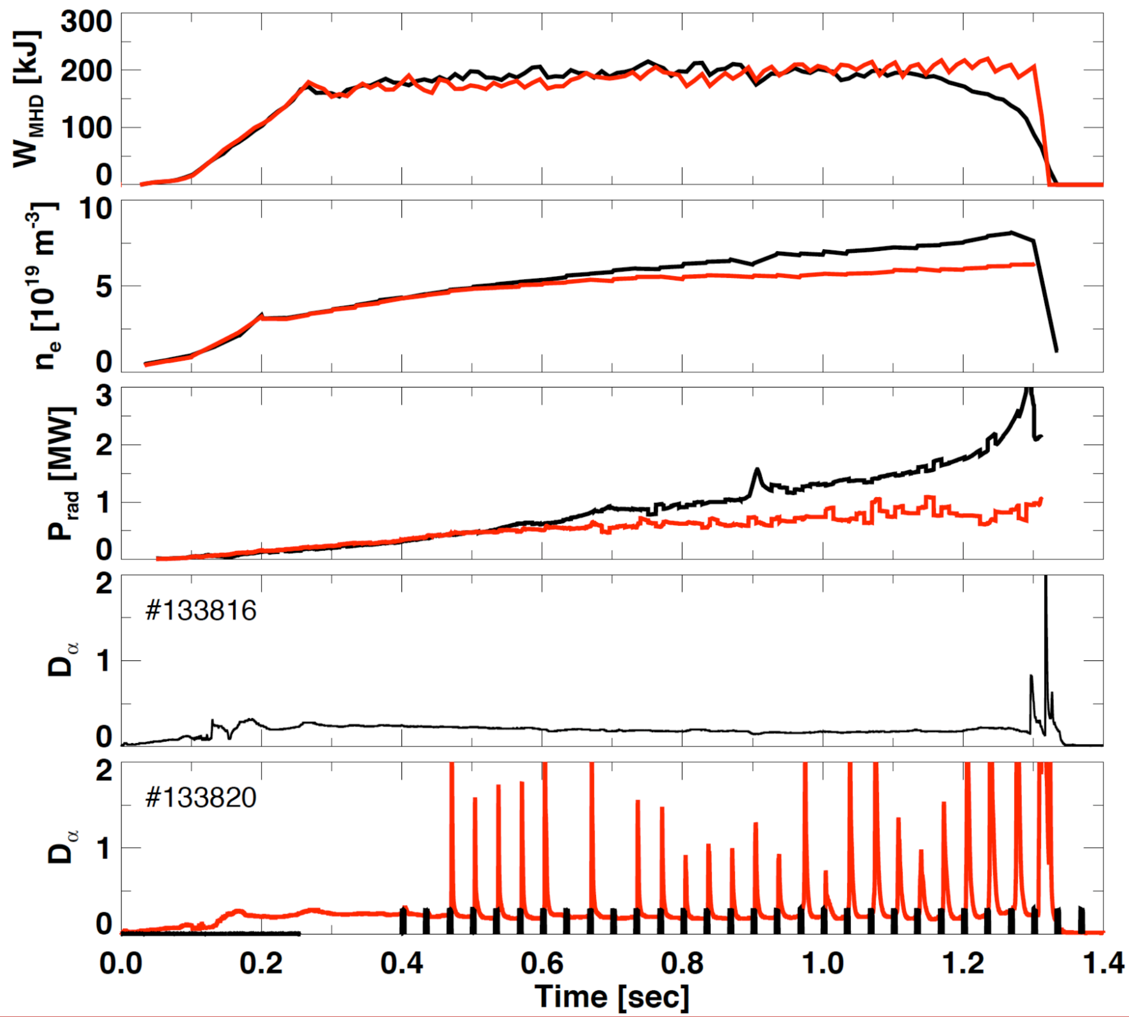
Lithium wall coatings modify edge transport and stability in NSTX

- ELM-free phases increase gradually with lithium deposition, with discharges eventually becoming ELM-free
  - n_e profile shifts inward gradually with increasing lithium
  - T_e, T_i increase and profiles change substantially
- H-factor increased up to 50% for thickest lithium coatings
  - Region of low D, χ_{eff} extends inward from H-mode barrier
  - Global stability limits (β_N ~ 5.5-6) encountered before edge (ELM) stability limits
- Peak pressure gradients shifted inward -> ELMs suppressed
  - Density profile modification crucial step toward ELM suppression
- *Impurities accumulate and radiated power increases monotonically in the discharge*

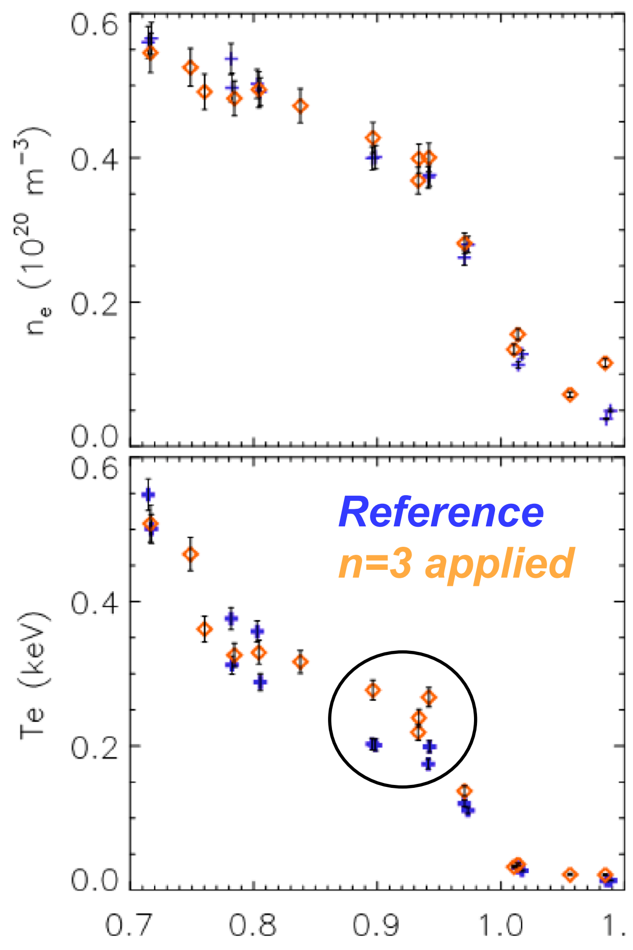
  ➢ Present remedy: use 3d fields to trigger ELMs to purge impurities while looking to reduce impurity influx, e.g. via 'snowflake' divertor

3D external fields used to trigger ELMs, prevent radiation buildup while keeping high energy confinement from lithium

Type I ELMs triggered for impurity control (post-lithium, n=3)



Edge T_e and dT_e/dr increased --> n=3 more unstable (PEST)



J. Canik, PRL 2010

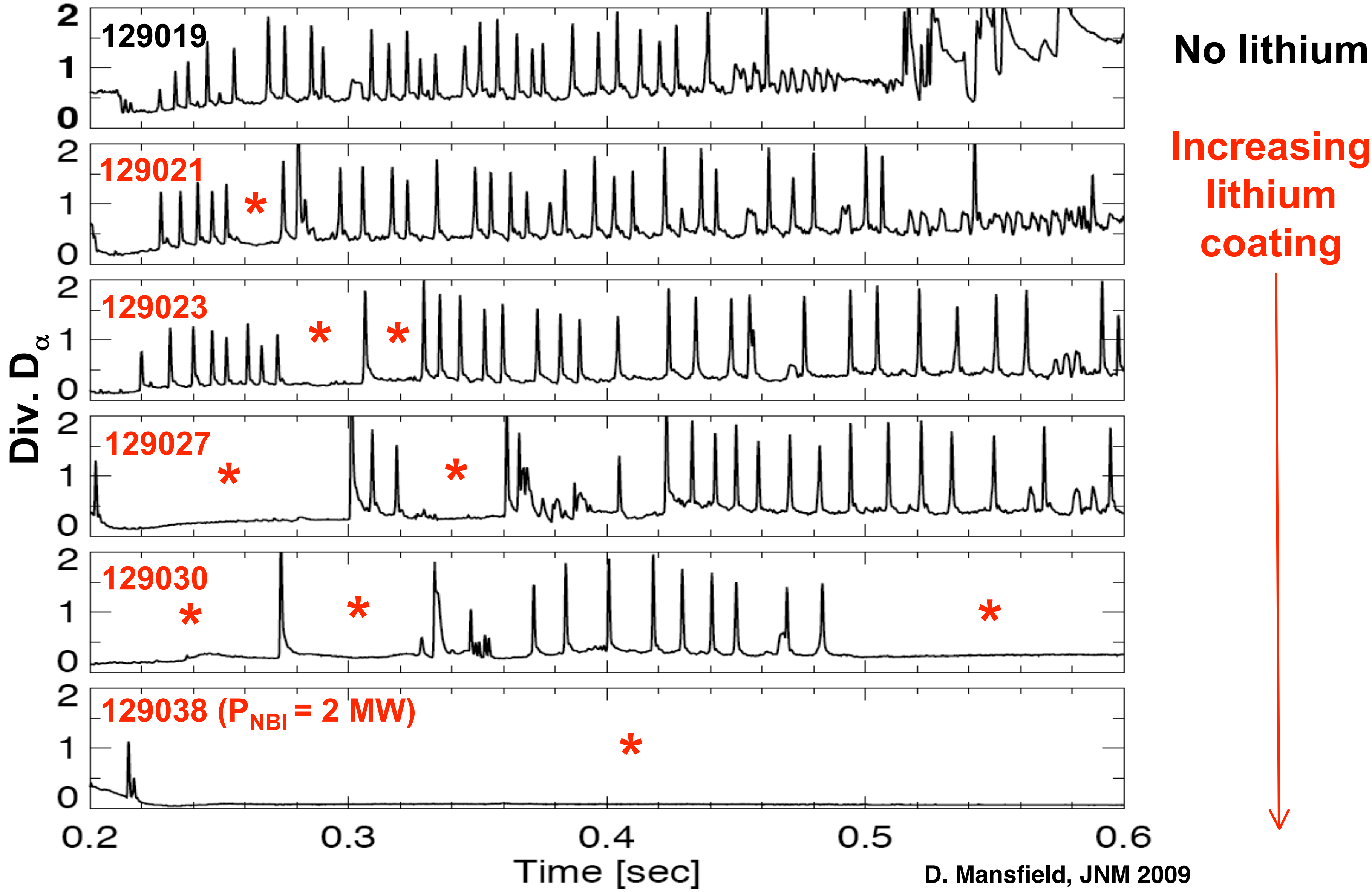
THANK YOU FOR YOUR ATTENTION!

- Mueller – O3.110 - Coupling of Coaxial Helicity Injection plasma start-up to inductive ramp-up on the NSTX
- Gerhardt - O5.126 - Development of High-Elongation, High-beta Discharges for Steady State ST Application

- Ahn – P2.113 – Effect of 3d fields on divertor profiles in NSTX
- Canik – P2.123 – Impurity control with 3D fields in NSTX
- Gray – P2.132 – Heat flux width scaling in NSTX
- Menard – P2.106 – NSTX-U physics design
- Sontag – P2.160 - Small-ELM Regimes in NSTX
- Soukhanovskii – P2.161 – Snowflake divertor experiments
- Sabbagh – P4.160 – RWM stability at high beta in NSTX

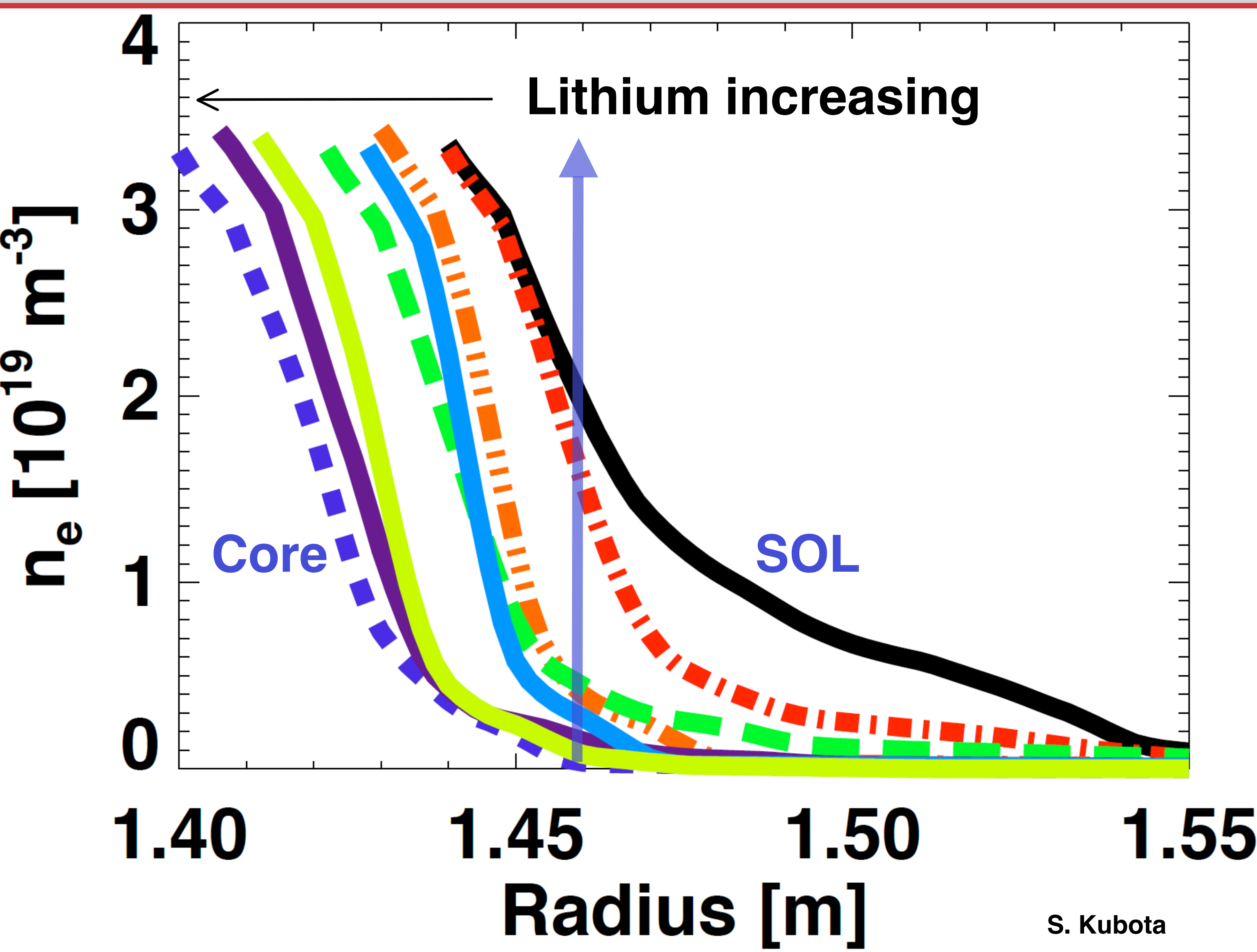
BACKUP

Quiescent phases (*) increase with increasing lithium coating (P_{NBI} = 4 MW)



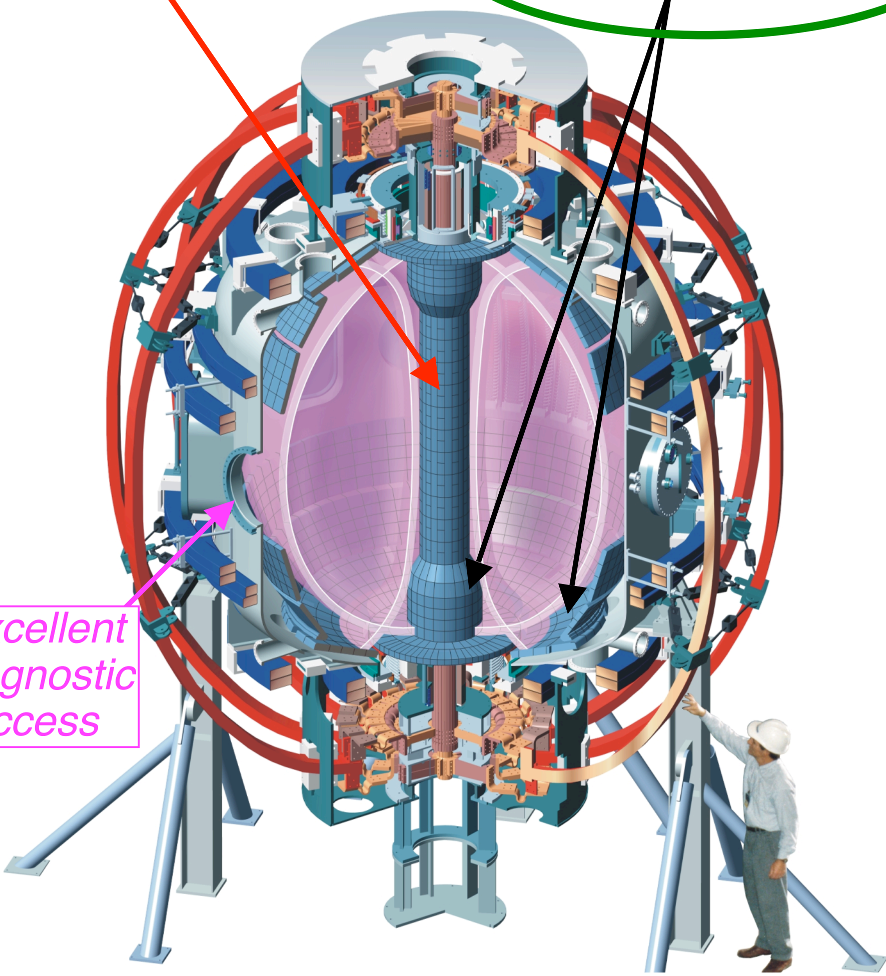
D. Mansfield, JNM 2009

Density profile shifted inward near the magnetic separatrix



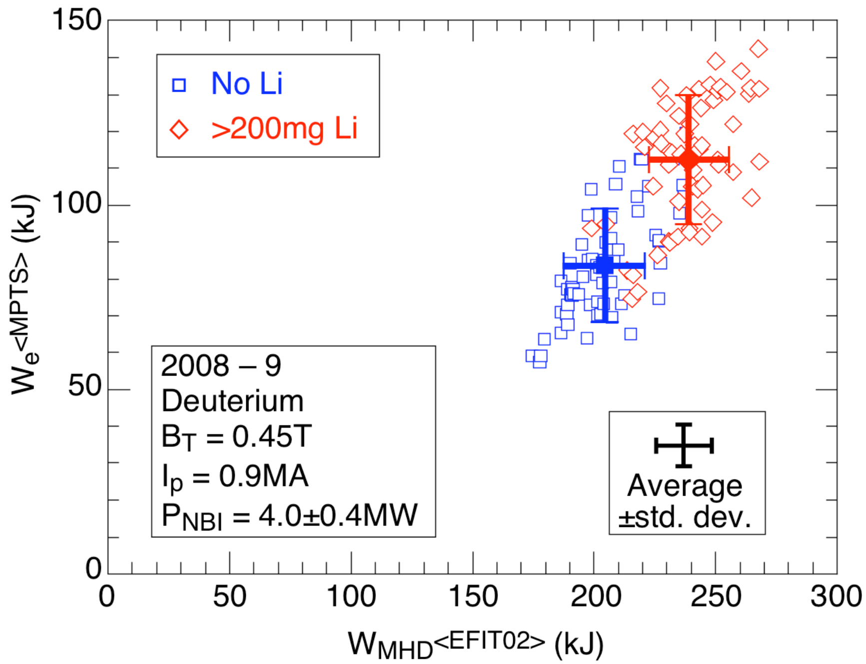
S. Kubota

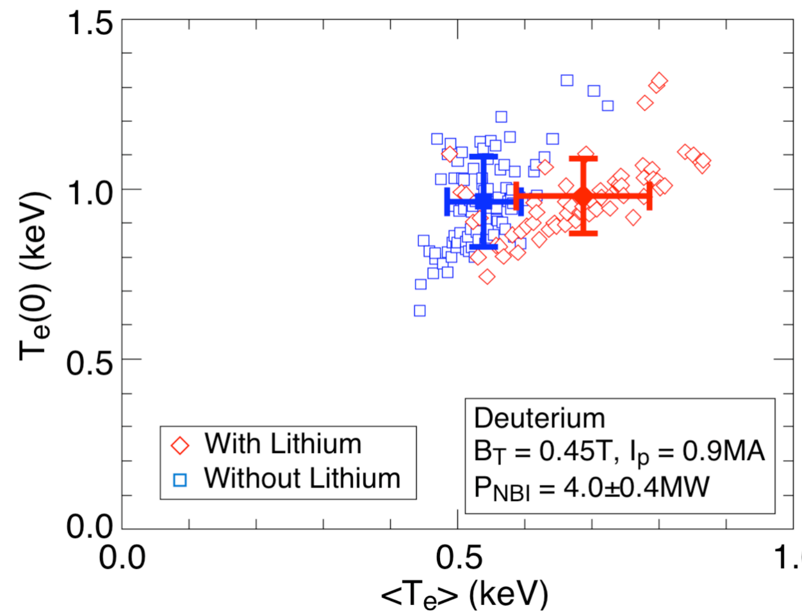
NSTX Facility Capabilities

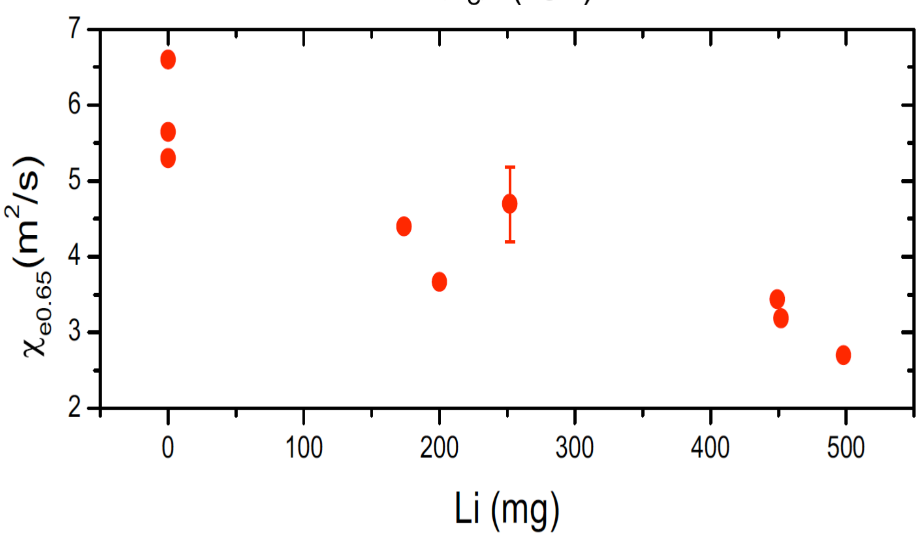


R, a_{max}	0.85, 0.67 m
Aspect ratio A	1.27 – 1.6
Elongation κ	1.6 – 3.0
Triangularity δ	0.3 – 0.8
Toroidal Field B_{T0}	0.3 – 0.55 T
Plasma Current I_p	≤ 1.5 MA
Auxiliary heating:	
NBI (100kV)	≤ 7.4 MW
RF (30MHz)	≤ 6 MW
Central temperature	1 – 6 keV
Central density	$\leq 1.2 \times 10^{20} m^{-3}$

Confinement improves with lithium coatings, due to broadening of the temperature profiles







- TRANSP analysis confirms electron thermal transport in outer region progressively reduced by lithium

M. Bell EPS09, S. Ding PPCF at press

NSTX Developing Lithium-Coated Plasma Facing Components (PFCs)

2005: Lithium pellet injection for wall coatings

2006: LIThium EvaporatoR (**LITER**) deposited lithium on center column and lower divertor

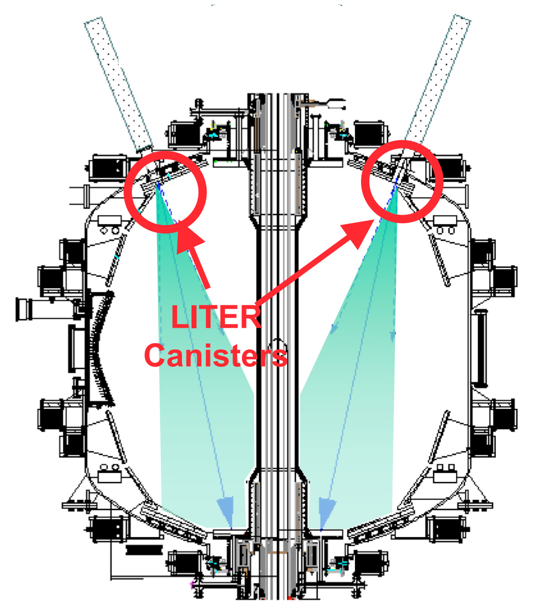
2007: Larger evaporator re-aimed to increase deposition rate on lower divertor

2008: Dual LITERs to eliminate shadowed regions

– Also used "lithium powder dropper"

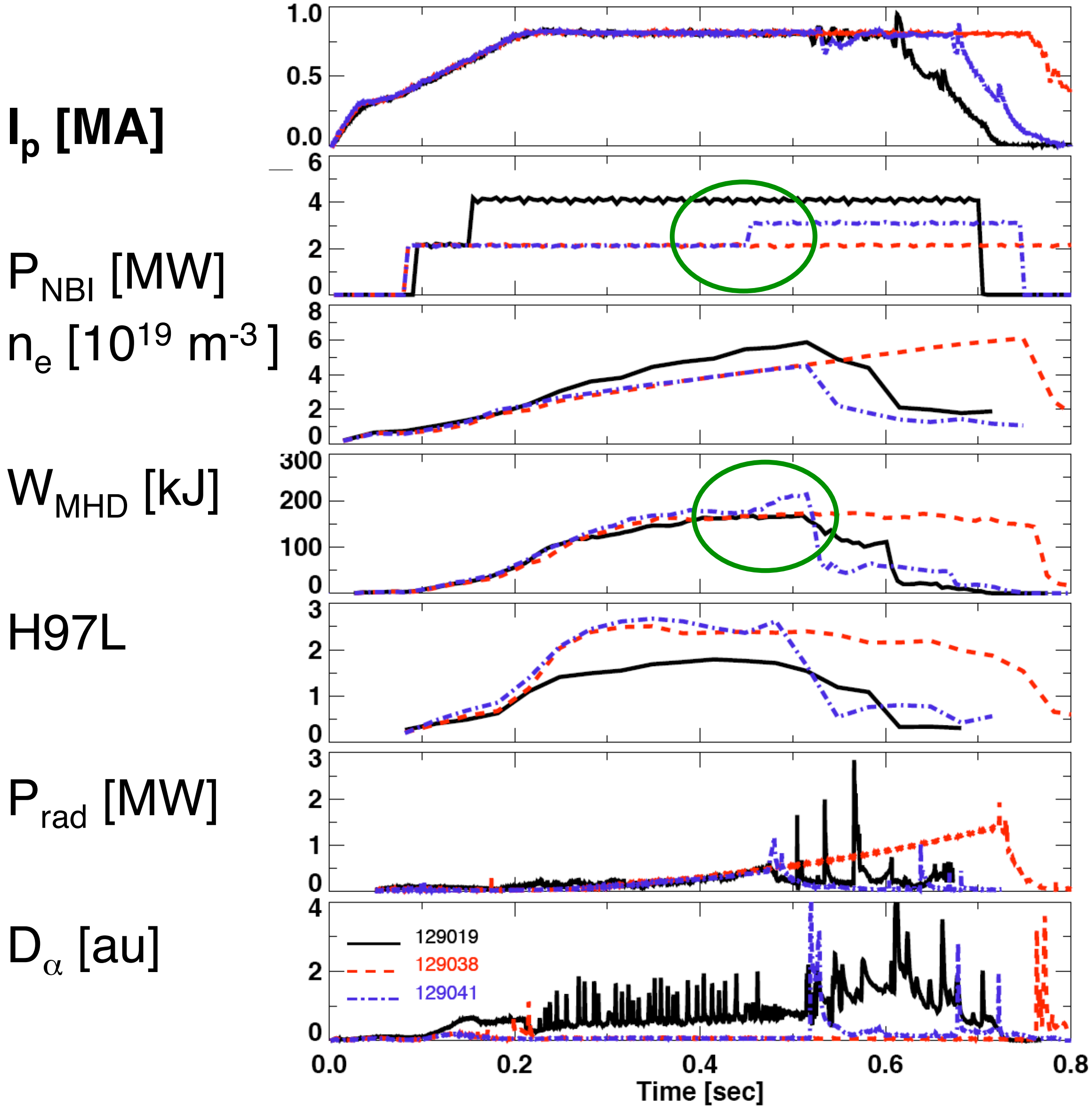
2009: Routine use of dual LITERs

- 80% of discharges now have lithium applied beforehand



- Complements and builds on experience with lithium coating of limiters in tokamaks TFTR, CDX-U (liquid), T-11, FTU, HT-7
  - Now also used in stellarator TJ-II

Global β_N limit encountered before edge stability limit with lithium coatings



- Pre-Li, Post-li, Post-li at β limit
- Intermediate NBI to probe β limit

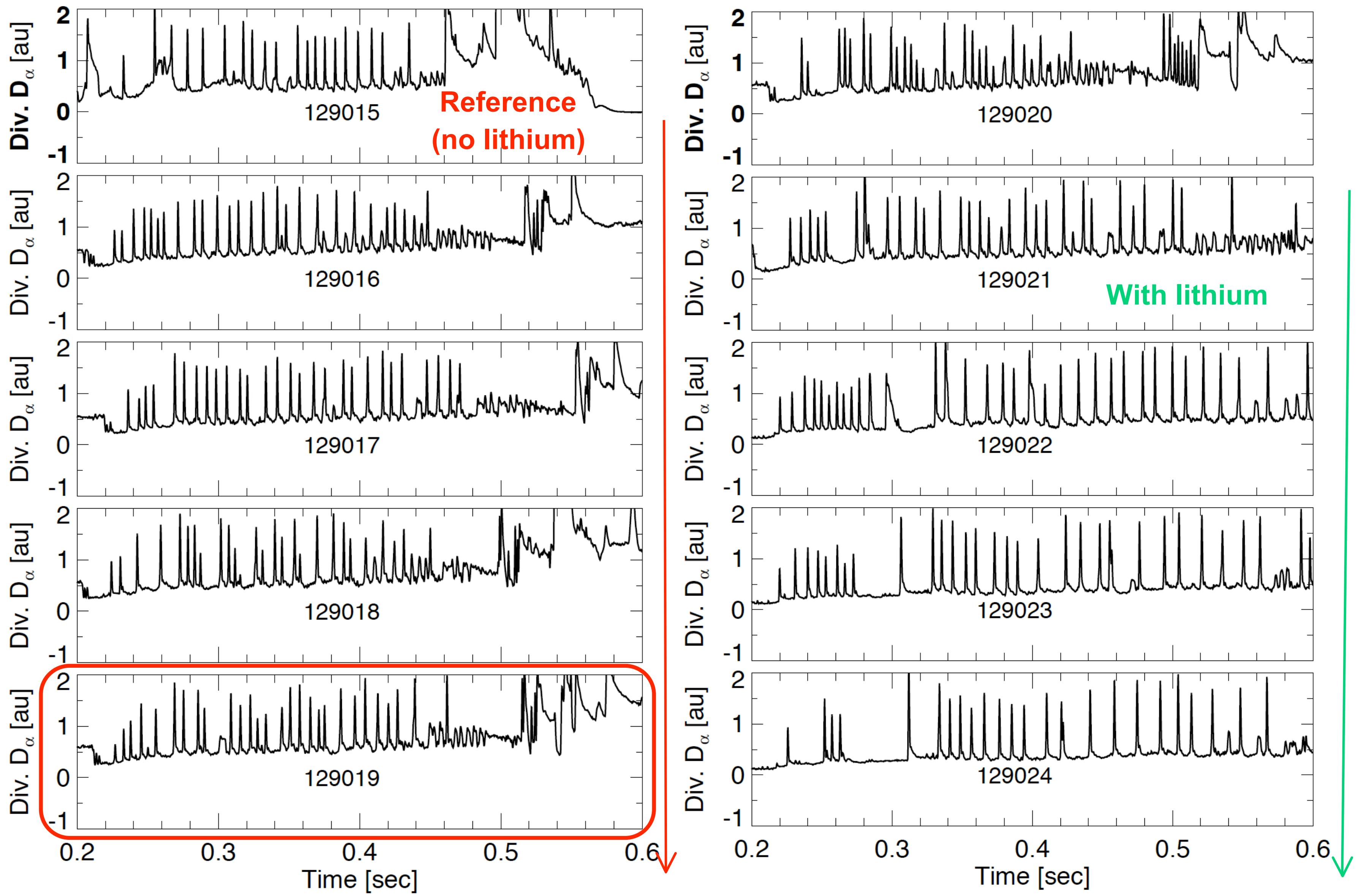
- β_N limit ~ 5.5 with P_{NBI}=3 MW

R. Maingi, PRL 2009

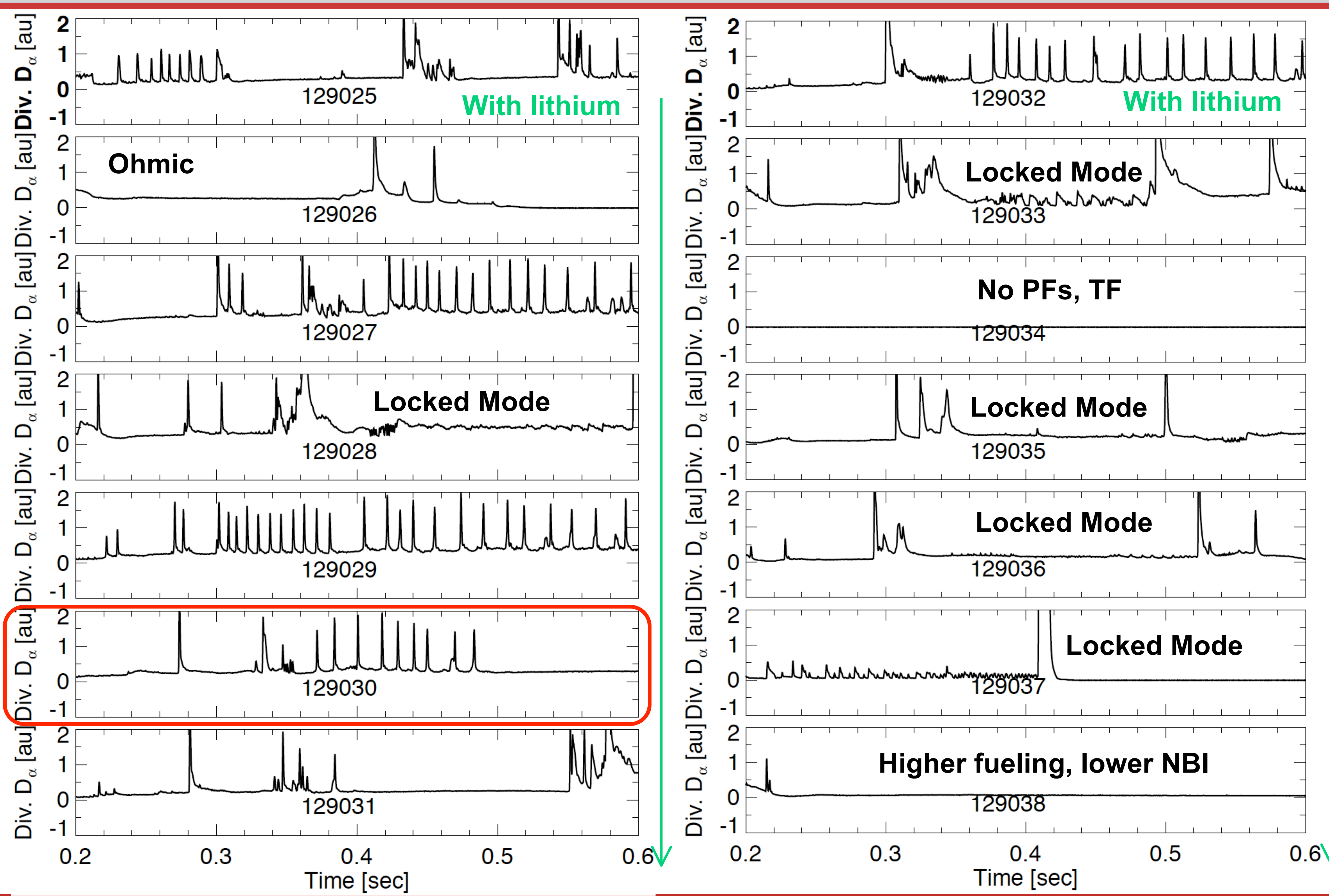
Suppression of all ELMs with lithium wall coatings

- ELMs disappear gradually, with reduced ELM frequency and growing periods of quiescence
- Edge n_e profile shifts inward by several cm, while edge T_e profile increases inside of edge n_e pedestal
  - Magnitude of the n_e profile shift increases with amount of lithium coating
  - 2D plasma + neutrals code SOLPS used to interpret changes in profiles
  - Observed n_e profile shift cannot be reproduced with simple reduction of divertor recycling coefficient

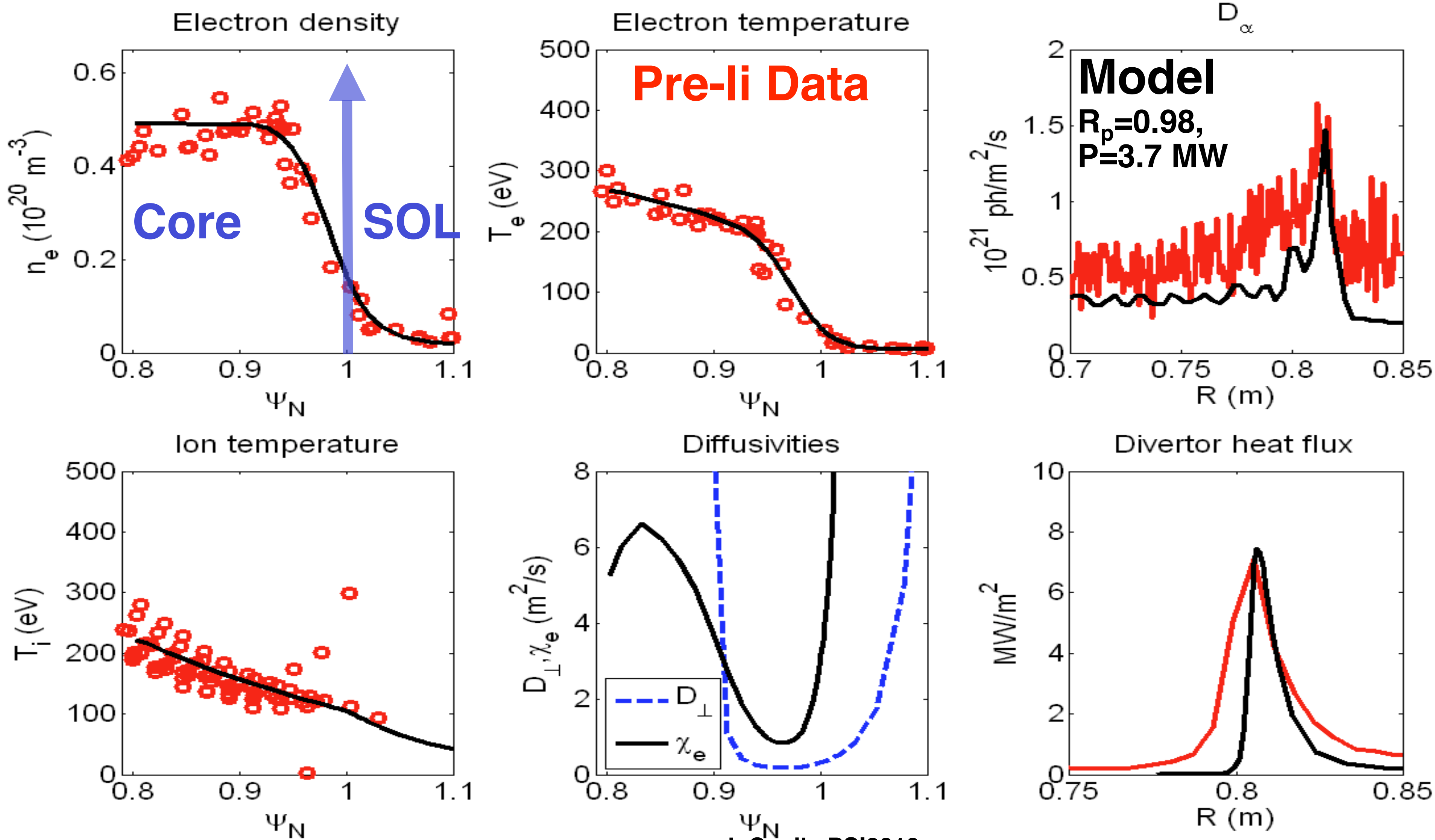
ELM evolution with shot number



ELM evolution with shot number

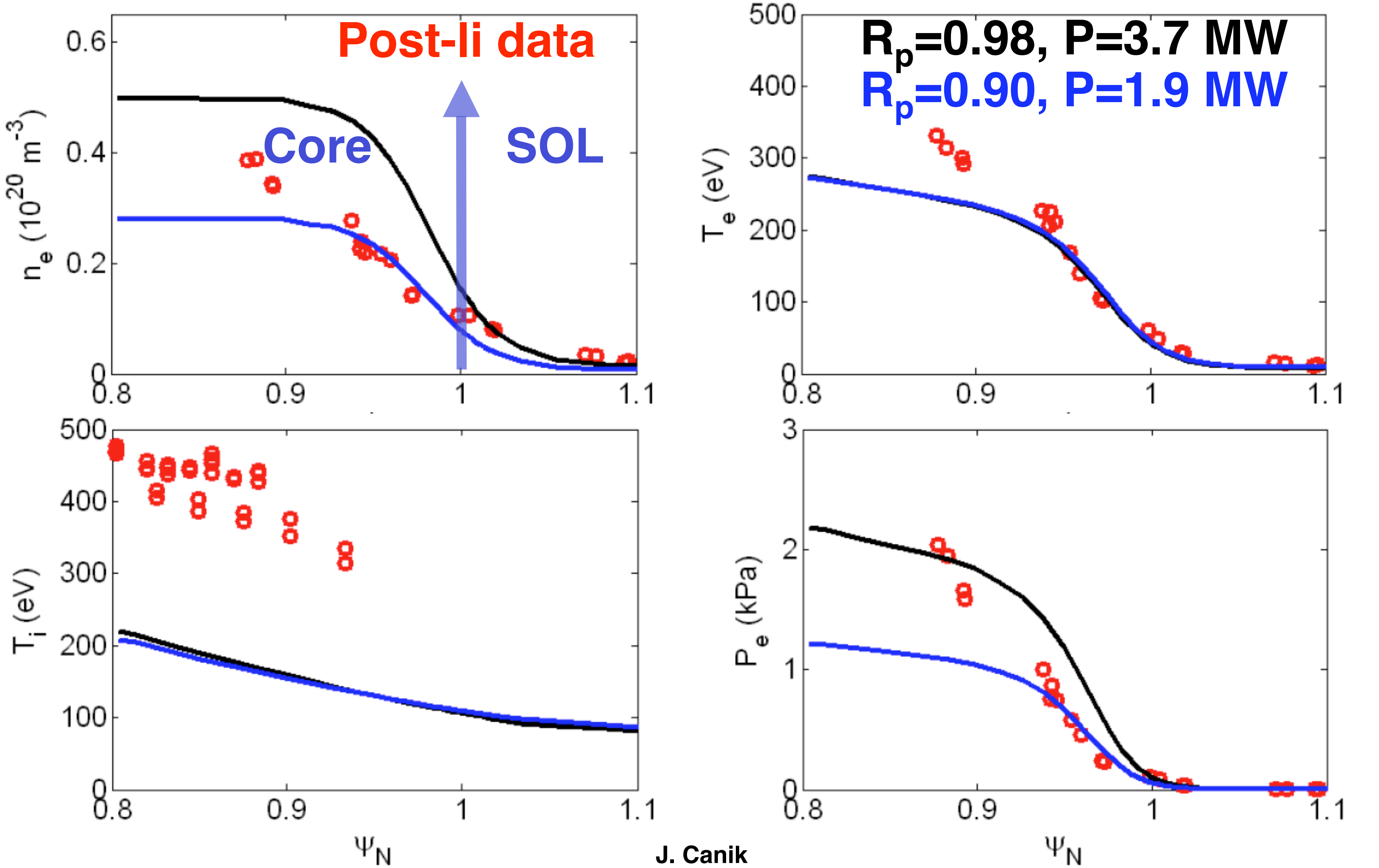


SOLPS modeling used to model power and particle balance of baseline ELMy discharge



J. Canik, PSI2010

Post-lithium discharge profiles not reproduced with simple recycling coefficient change



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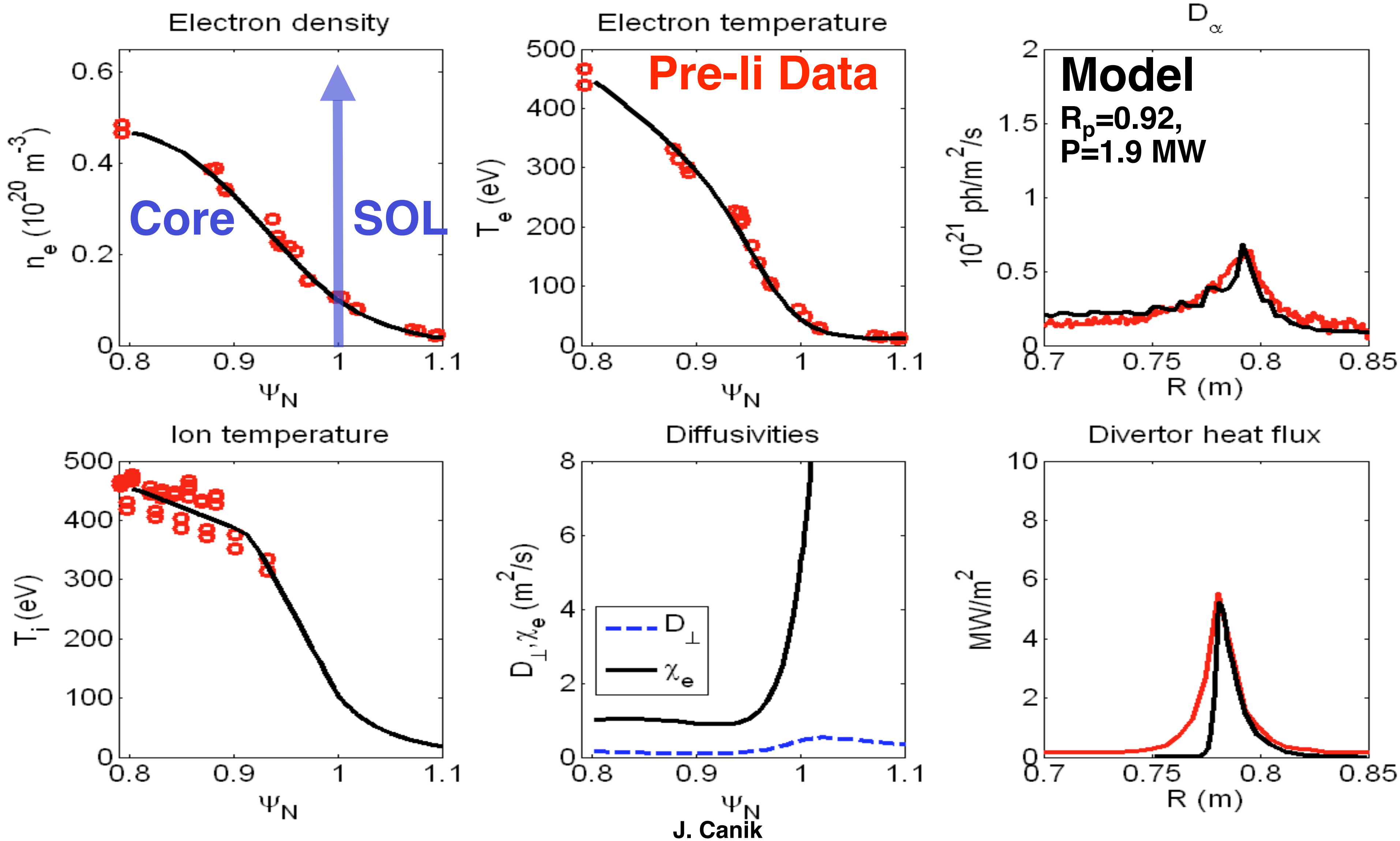
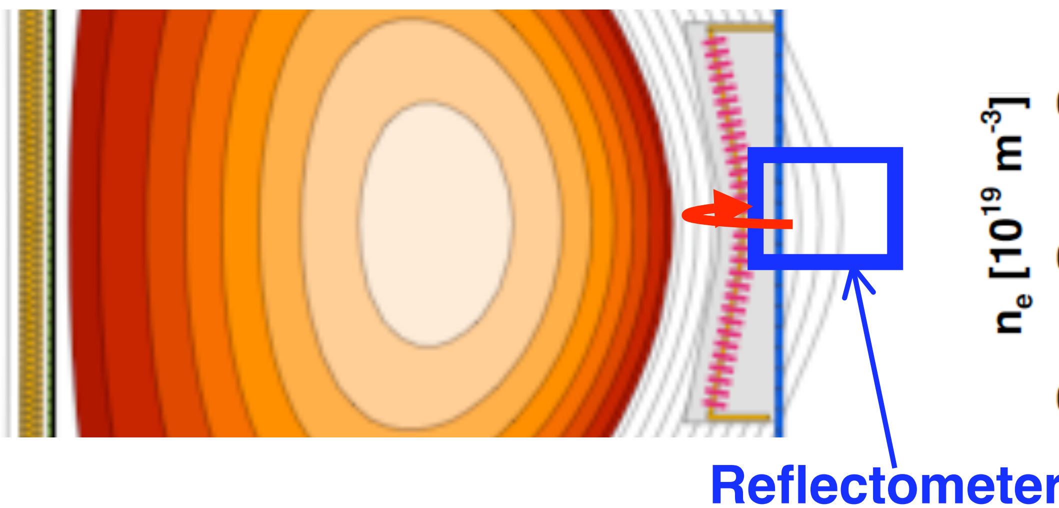
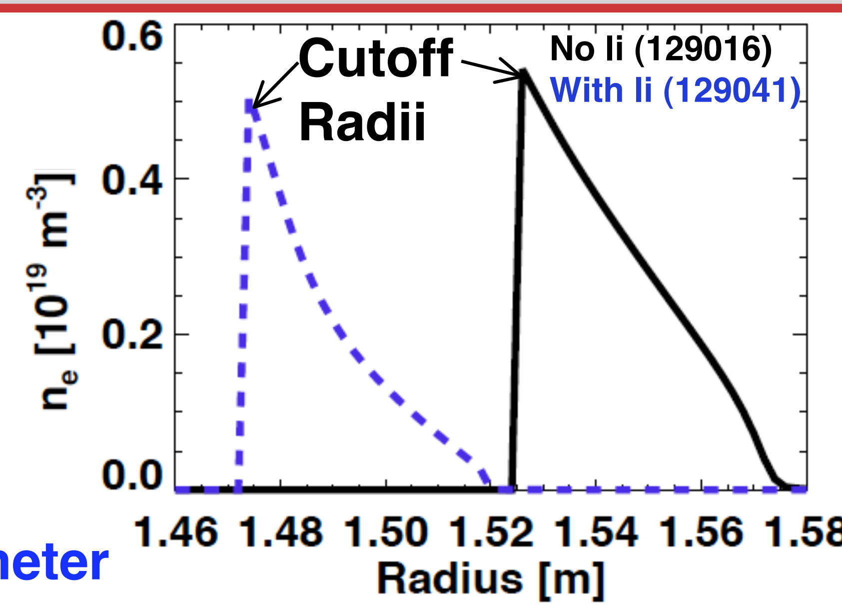
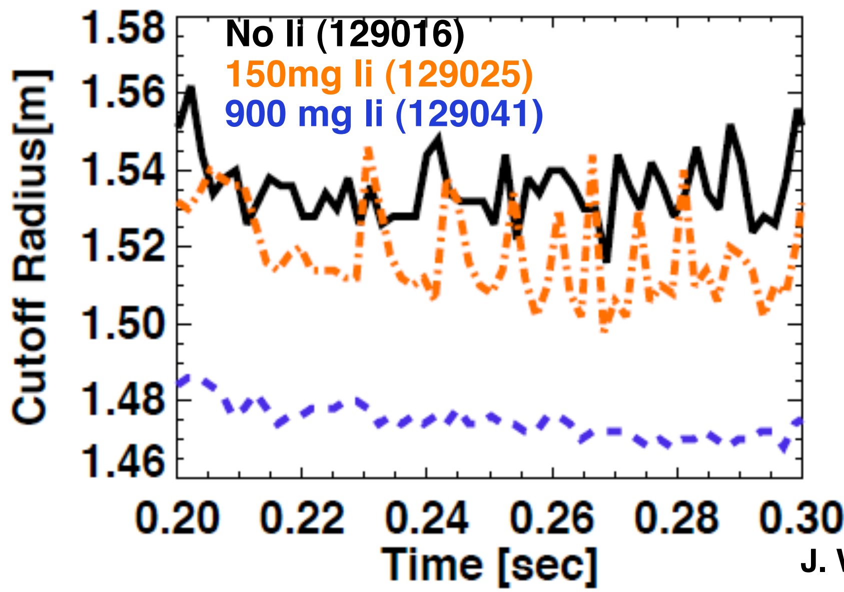
Post-lithium discharge profiles better matched with transport and recycling coefficient change



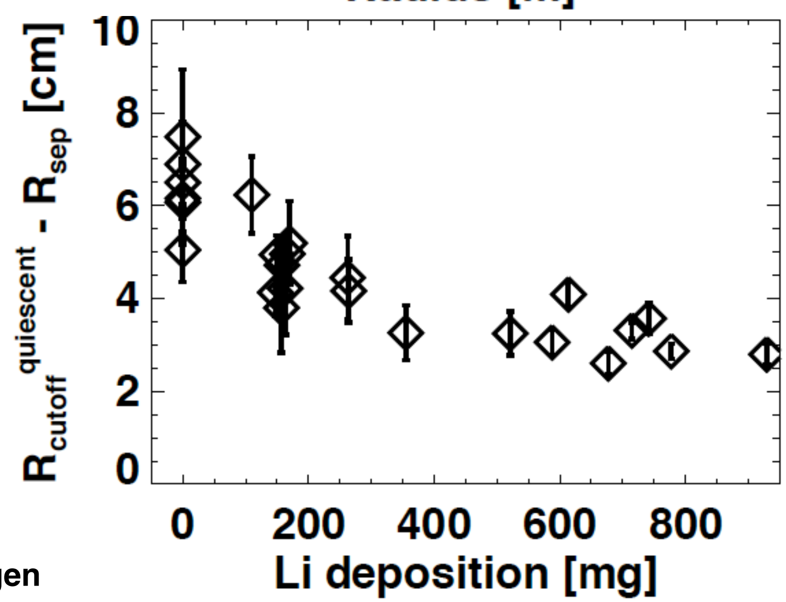
Radius at cutoff density moves close to separatrix with increasing lithium deposition





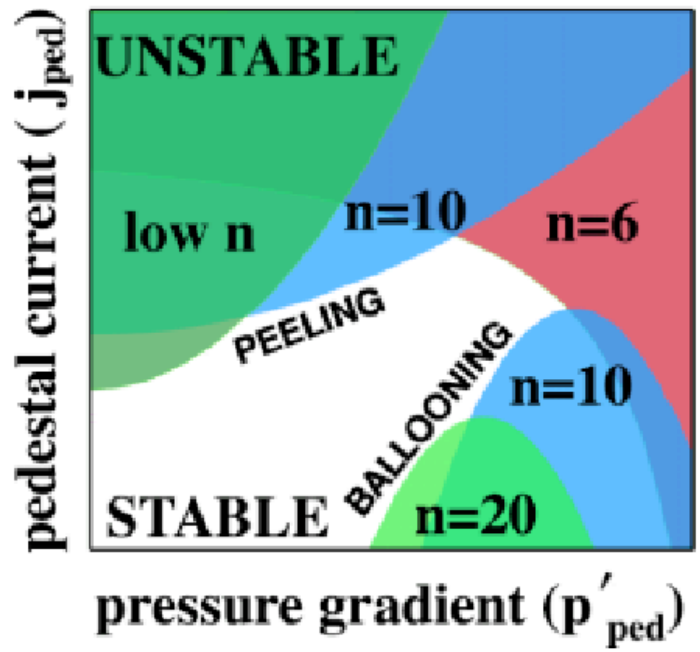


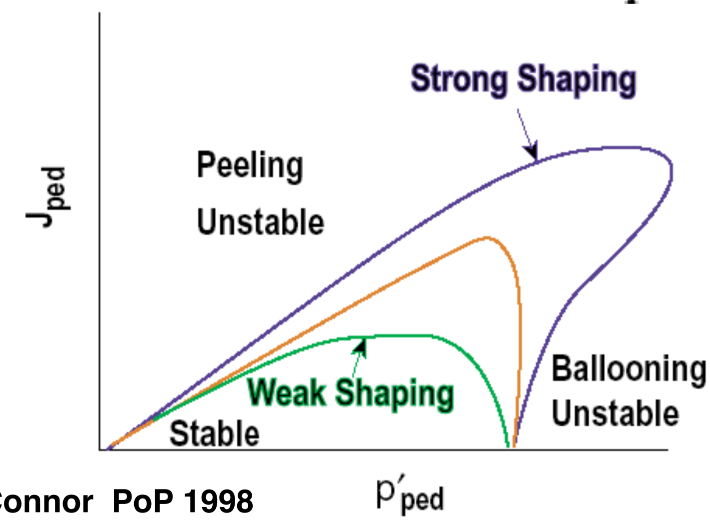
J. Wilgen



Edge stability window determined by kink/peeling and ballooning mode MHD instabilities

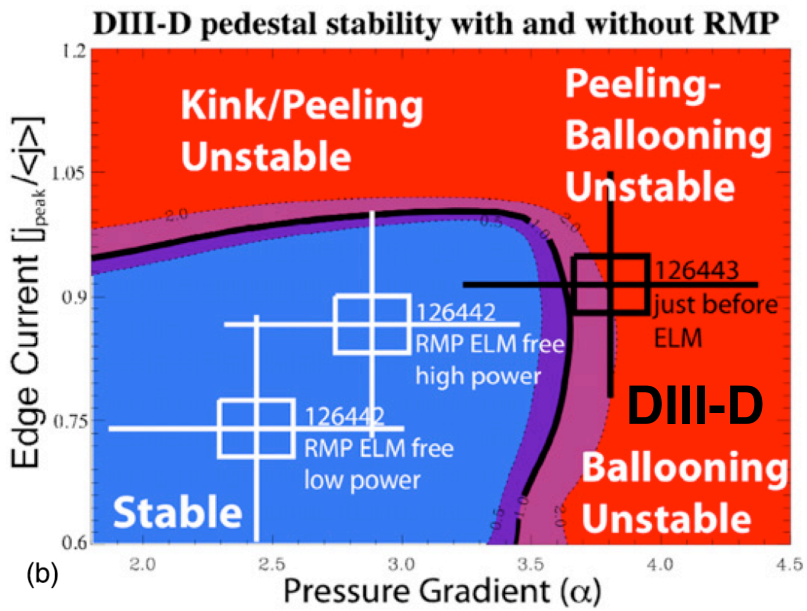
- Ballooning modes driven by plasma pressure gradient
- External kink/peeling modes driven by edge current
  - Modes couple at finite-n to form stability window
- Bootstrap current plays a complex role in edge stability
  - Driven by the pressure gradient
  - Largest component of the parallel current in the pedestal, j_{ped}
  - Destabilizes kink, peeling modes
  - Reduces local magnetic shear to open access to second stability regime

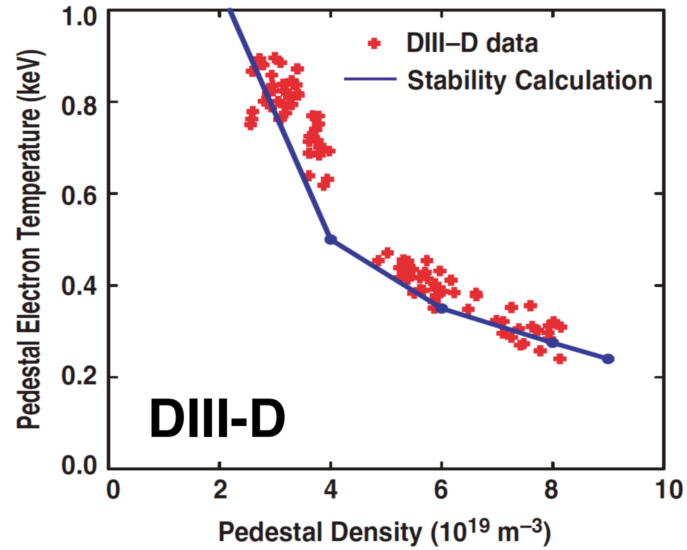


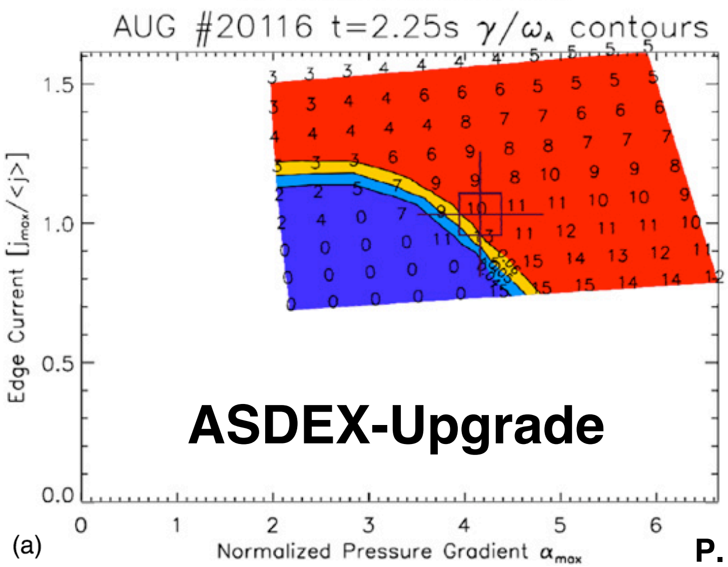


P. Snyder PoP 2002, H. Wilson PoP 2002, J. Connor PoP 1998

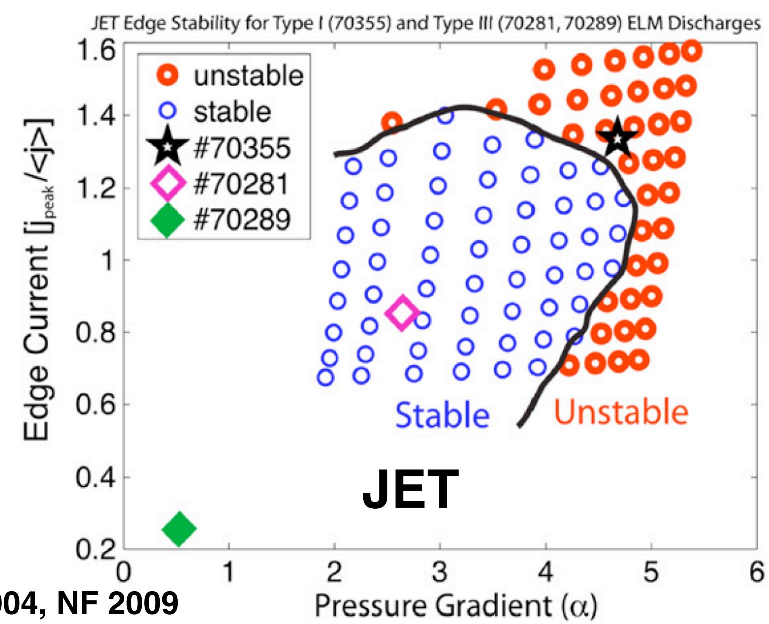
Peeling-ballooning constraint tested in several tokamaks



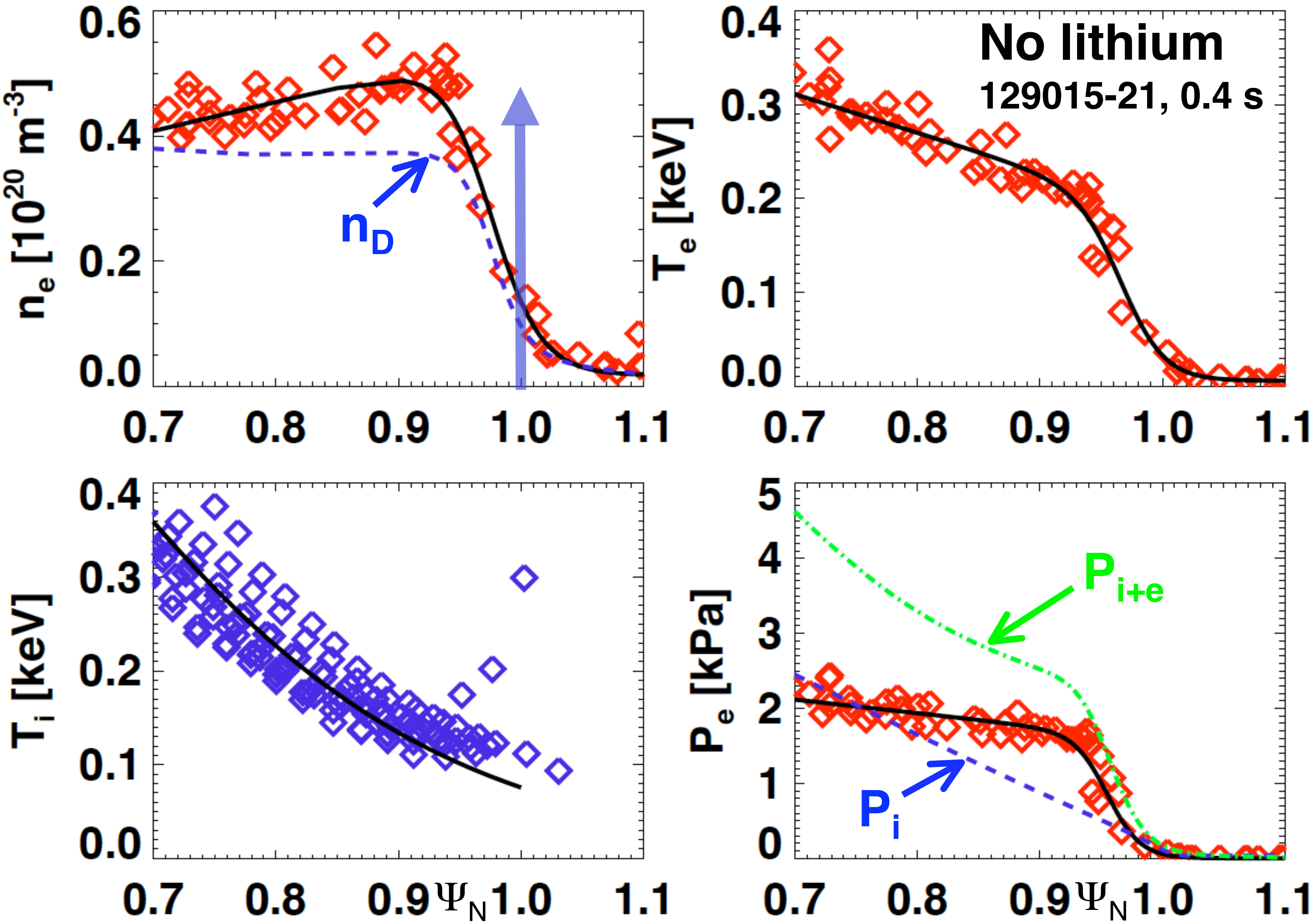




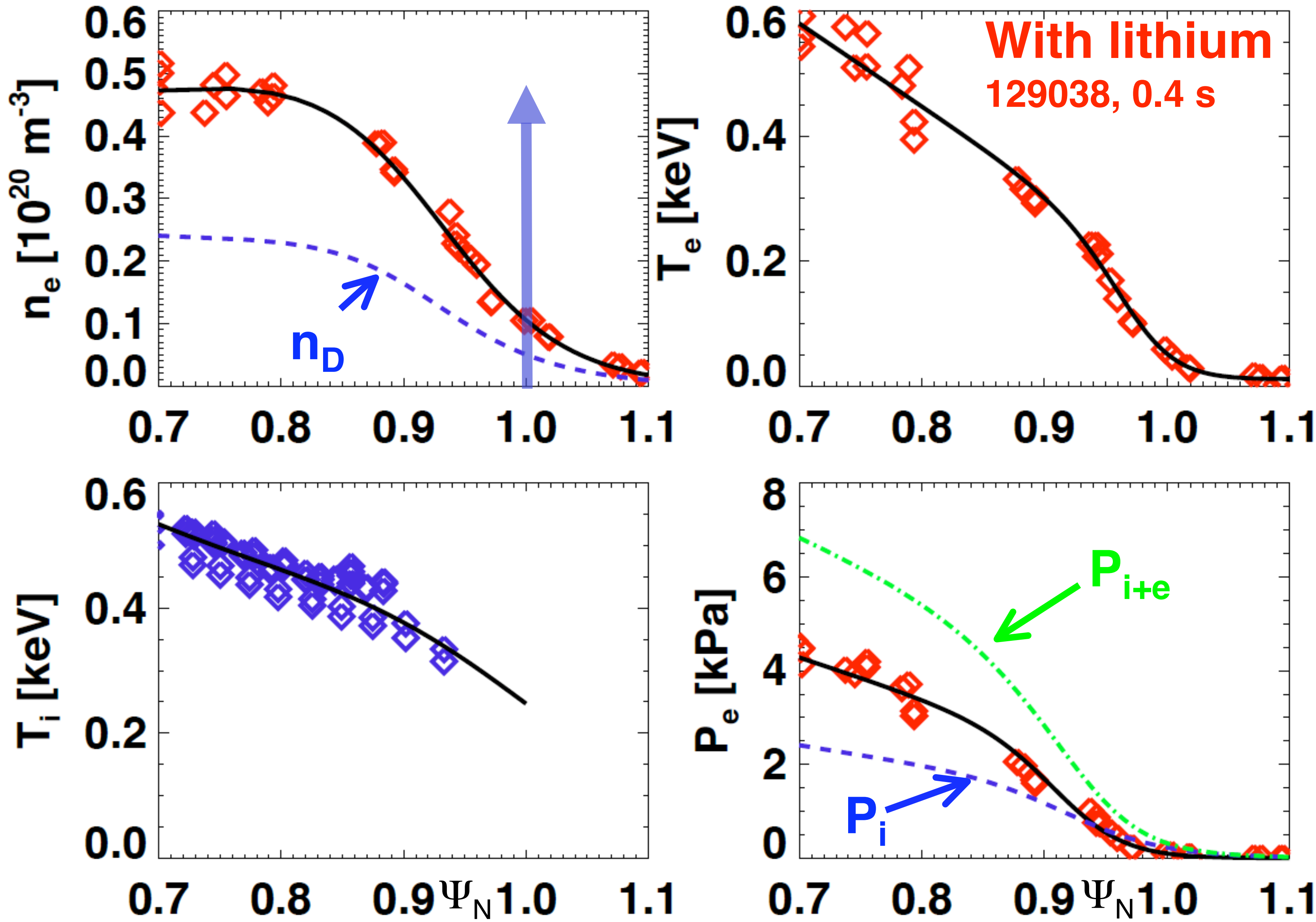
P. Snyder PPCF 2004, NF 2009



Electron pressure gradient dominates total pressure gradient



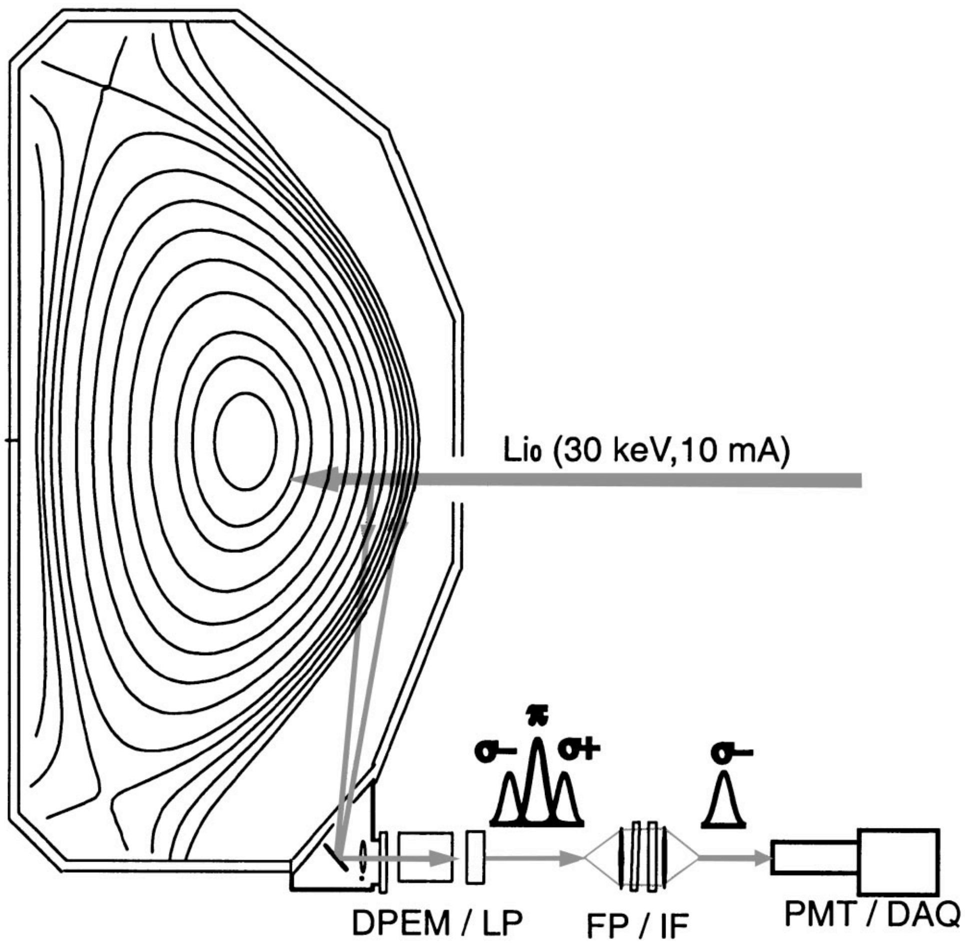
Electron pressure gradient dominates total pressure gradient

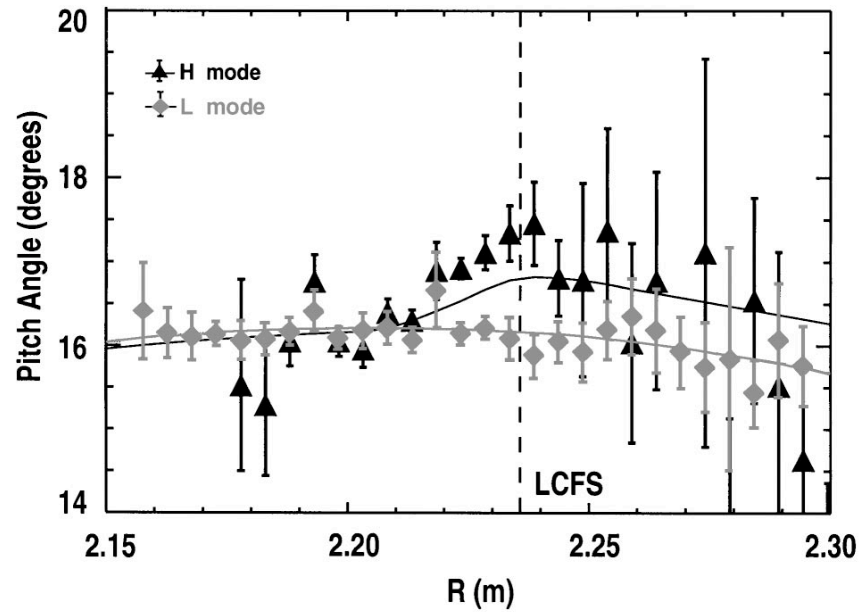


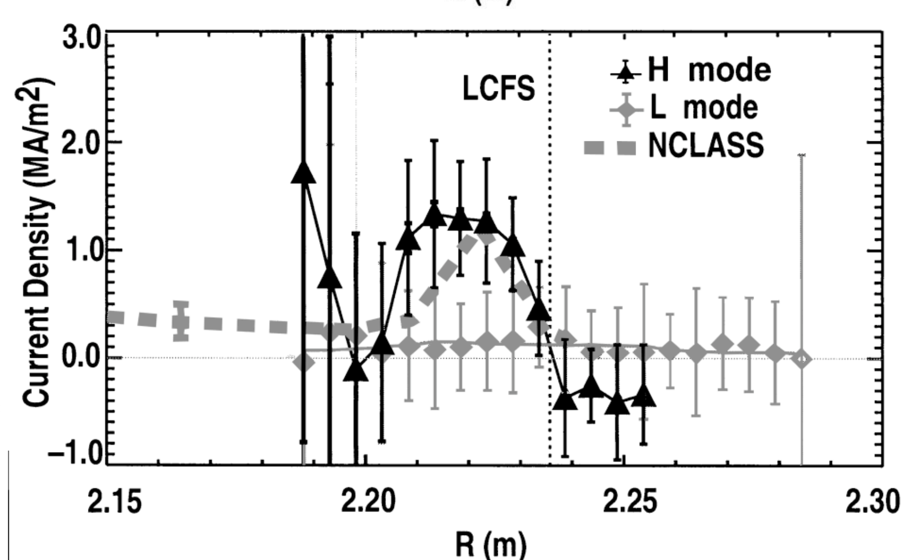
Details of precise evolution toward ELM suppression not well understood

- Why are the ELMs not stabilized by diamagnetic drift, as in higher aspect ratio tokamaks?
- Complete evolution: why do ELMs go away the way they do i.e. with increasing periods of quiescence?
- What is the role of failed discharges/L-mode in observing ELMs on following discharges?

Measured edge bootstrap current in reasonable agreement with neoclassical calculation in DIII-D







D. Thomas, PRL 2004